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**Supplementary Material**

The Mid-Lithospheric Discontinuity caused by channel flow of proto-cratonic mantle

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# 1. Methods

We model the long-term evolution of the Archean cratonic mantle by the particle-in-cell, finite-element, geodynamics code Underworld2 (Moresi et al., 2007)[, which solves the thermo-mechanically coupled conservation equations of mass and momentum:](#_ENREF_3)

|  |  |
| --- | --- |
|  | (1) |
|  | (2) |

where is velocity, is deviatoric stress, is pressure, is density and is gravitational acceleration. For the equation of conservation of mass (1), we assume incompressibility condition. Lateral and secular changes in temperature are incorporated through the heat conservation equation:

|  |  |  |
| --- | --- | --- |
|  | (3) |  |

where is density, is heat capacity, is thermal conductivity and is heat production (only radioactive heat sources are considered). The model domain is a rectangular box with a dimension of 4000 km x 660 km (Fig. 2a), which is resolved on 540 x 240 bilinear elements. We adopt edge-parallel free slip and edge-normal zero slip at all four boundaries. The model parameters for the three model layers (crust, lithospheric mantle, and sublithospheric mantle) are specified in Table S1; and we assume that density and thermal conductivity are temperature dependent.

Non-Newtonian viscous deformation in the mantle is specified by:

|  |  |  |
| --- | --- | --- |
|  | (4) |  |

where is strain rate, a material constant, the stress exponent, the activation energy, the activation volume, and the gas constant. Mantle dehydration due to melt extraction during craton formation may increase the viscosity of the cratonic root (Hirth and Kohlstedt, 2003)[.](#_ENREF_2) Therefore, we assume that at the same strain rate and temperature, the intrinsic viscous strength in the sub-lithospheric mantle is 1/5 of that in the lithospheric mantle. The effective viscosity is given by

|  |  |
| --- | --- |
|  =  | (5) |

where and are the square roots of the second invariants of stress and strain rate, respectively. The effective viscosity is restricted to the range between 1018 Pas and 1024 Pas.

# 2. Table S1. Parameters of the end-member model (Figure 2)

Density depends on temperature *T* as where is standard (SPT) density at .1MPaand K; = 1.0×10-5 K-1 is thermal expansion; is temperature-dependent thermal conductivity, and is heat capacity.

The results for reference model evolution are shown in Figures 3-4. Models with other parameters are tested as well (Table S2, Figures 5-8, S2-S3).

|  |  |  |  |
| --- | --- | --- | --- |
|  |  Crust | Lithospheric Mantle | Sub-lithospheric Mantle |
| Wet quartzite[1] | Dry olivine[2] | Dry olivine[2] |
|  (MPa-n S-1) | 3.2×10-4 | 1.585×103.5 | 1.585×103.5 |
|  | 2.3 | 3.5 | 3.5 |
| kJ/mol | 154 | 510 | 510 |
| (cm3/mol) | 0 | 11 | 11 |
|  (kg/m3) | 2700 | 3300 | 3330 |
| (W/mK)[3] | 0.64+807/(T+77) | 0.73+1293/(T+77) | 0.73+1293/(T+77) |
| (μW/m3) | 1 | 0.2 | 0.02 |
| *Thickness* (km) | 40 | 55 and 195 | 565 and 425  |
| *Depth to bottom* (km) | 40 | 95 and 235 | 660 |

[1] [Ranalli (1995)](#_ENREF_4); [2] [Hirth and Kohlstedt (2003)](#_ENREF_2); [3] [Clauser and Huenges (1995)](#_ENREF_1).

# 3. References to Methods and Table S1

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# 4. Table S2: Model codes and model parameters

Parameters of the reference model are listed in Table S1 and are illustrated in Figure 2. The results for end-member model evolution are shown in Figures 3-4.

|  |  |  |
| --- | --- | --- |
| Model code | Difference with the reference model | Figure with model evolution |
| N/A | 1. CLAB in thin proto-CBL domain is initially 95-210 km thick (95 km in the end-member model).
2. Thermal expansion coefficient 3×10-5 K-1 (1×10-5 K-1 in the reference model).
 | Fig. 5 |
| N/A | 1. CLAB in thin proto-CBL domain is initially 210 km thick (95 km in the reference model). 2. Thermal expansion coefficient 3×10-5 K-1 (1×10-5 K-1 in the reference model).3. Viscosity in sublithospheric mantle is reduced by a factor of 5 of the end-member model | Fig. 6 |
| N/A | A broad thick-thin proto-CBL domain transition at x = 800-2600 km (the reference model has a narrow transition at x = 2400-2600 km). | Fig. 7 |
| M\_den15\_exp2 | 1. Density contrast across the CLAB is 15 kg/m3 (30 kg/m3 in the reference model).
2. Thermal expansion coefficient 2×10-5 K-1 (1×10-5 K-1 in the reference model).
 | Fig. 8, 9c |
| M\_den05\_exp3 | 1. Density contrast across the CLAB is 5 kg/m3 (30 kg/m3 in the reference model).
2. Thermal expansion coefficient 3×10-5 K-1 (1×10-5 K-1 in the reference model).
 | Fig. 9b |
| N/A | Temperature profile in the lithospheric mantle is limited by solidus temperature. | Fig. S2a, wet solidus;Fig. S2b, dry solidus |
| N/A | Thermal expansion coefficient 3×10-5 K-1 (1×10-5 K-1 in the endmember model). | Fig. S3a |
| N/A | 1. The model accounts for the effect of latent heat.
2. Thermal expansion coefficient 3×10-5 K-1
 | Fig. S3b |
| N/A | 1.TLAB is initially at depth of 150 km (90 km in the endmember model). 2. Thermal expansion coefficient 3×10-5 K-1 | Fig. S3c |

# 5. References to Figure 1

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# 6. Supplementary Figures S1-S3

**Figure S1**. Relative heat production in the Earth for the past 4.5 Gy. The assumed present abundances for K, Th, and U are 200 ppm, 74 ppb, and 20 ppb, respectively. The weight percentage of 40K/K, 232Th/Th, 235U/U and 238U/U is 0.0119, 100.0, 0.71 and 99.28, respectively (Van Schmus, 1995). 40K and 235U provide the major contribution to heat production in the early Earth.



**Figure S2.** Snapshots of the model evolution for different temperature fields at time zero. Snapshots show the square root of the second invariant strain rate. Model settings are the same as in the end-member model, except that the temperature (white panel inserts) in the lithospheric mantle is lowered to the corresponding solidus temperature (Katz et al., 2003) when it reaches (**a**) wet solidus with 300 ppm water or (**b**) dry solidus. Even in the case of wet solidus (**a**), the model evolution produces a large-scale channel flow (> 1000 km) in the thick continental root.



**Figure S3**. Snapshots of the model evolution with the square root of the second invariant strain rate.

(**a**) Model parameters are the same as in the end-member model, except for higher value of the thermal expansion coefficient of 3×10-5 K-1.

(**b**) The same parameters as in (a) except the initial temperature at time zero is the same as in Fig. S2b (insert), so that the model accounts for the effect of latent heat. After the same time of model evolution as in Figure 2b (the endmember model), the channel flow forms in the lower lithospheric mantle in the entire model domain with a pressure difference of more than 20 MPa.

(**c**) The same parameter as in (a) except that the TLAB is initially at depth of 150 km, instead of 90 km as in the endmember model. The channel flow is observed as well, but the top of shear zone s1 is at a depth of ~150 km, which is deeper than that in the endmember model.